ECEN 5833: Low Power Embedded Design Techniques

CUBIT

Smart Measuring Instrument

Team Name: Cubit

Team Members: Rajat Chaple

Saloni Shah

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Project Proposal

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Background:

A measuring tape is used in a myriad of commercial businesses like construction, tailoring, warehouses as well as in day-to-day life. The first standard measuring tape was invented in 1850s and till now we have been using the same product. Although, since 18^{th} century the world has advanced in every possible way, we still use the same measurement technique. The conventional measuring tape has ample of drawbacks like taking and maintaining measurements is very tedious, also all the measurements taken are majorly single use. It is high time that we modernize our method of taking measurements and digitize the data which can be easily stored and accessed from anywhere.

Project Summary:

For the course project, our team is designing a smart measuring instrument which will have the capability to take precise linear and angular measurements and transmit the data over to a mobile application using Bluetooth. Primarily, this device will have an encoder-wheel assembly which can be used to take measurements over a straight or curved surface very accurately. A high precision rotary encoder will be helpful in giving high resolution results. Moreover, we will also install an inertial measurement unit (IMU) sensor to take different angular and device orientation data. Both measurements can then be transmitted to a mobile app connected to the product using Bluetooth. This data will also be displayed on an LCD. This device will run on a small battery, and it will also contain an energy harvesting system using solar panel to recharge the battery. All these components will be interfaced with a single Blue Gecko board. The device will operate in low power mode by implementing load power management and utilizing minimum current for required peripherals.

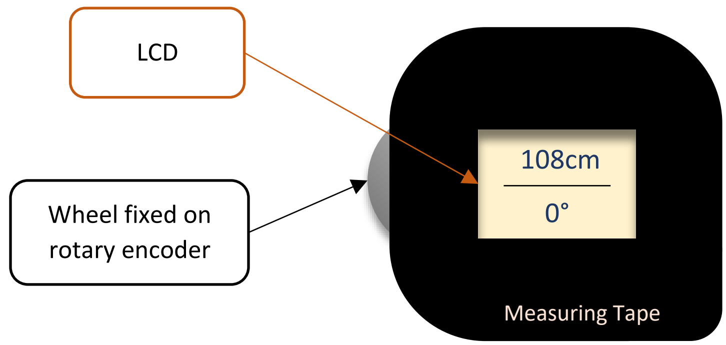
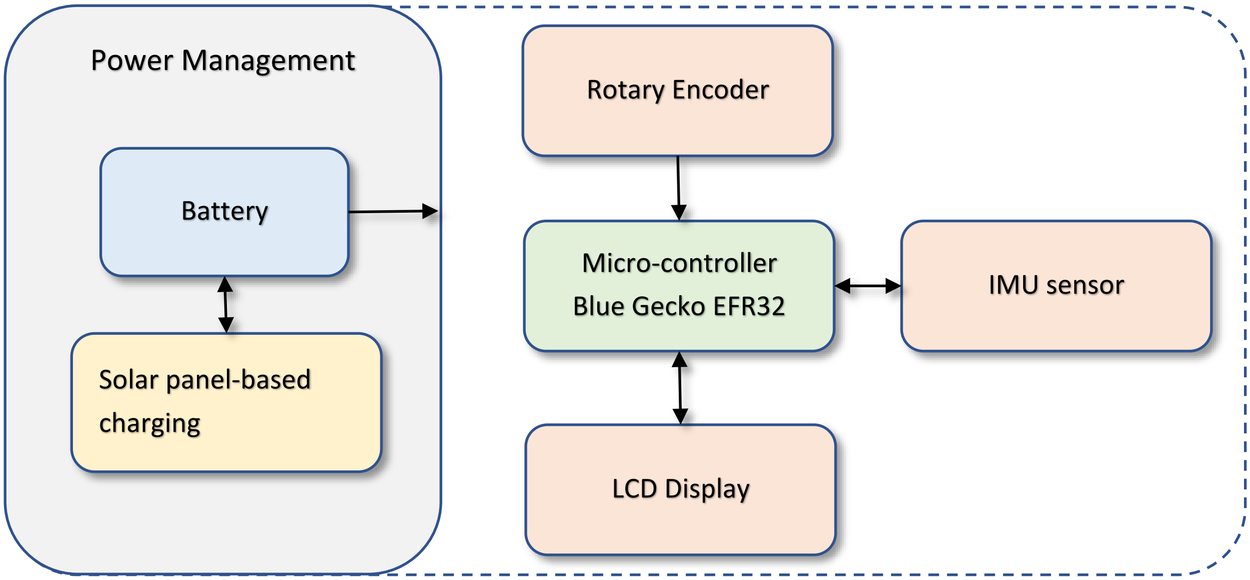


Fig 1: Product Concept

Product Application:

- This product can be used to fulfill majority of measurement requirements like taking size data of a straight or uneven surface and taking angle measurements.
- This product can be used in small industries, construction sites, fashion companies and regular households.
- This product will eliminate the need to manually store measured data.
- This product will be low cost, low power consuming with energy harvesting mechanism.
- This product will use long lasting rechargeable batteries unlike single usage dry cells.

Block Diagram:

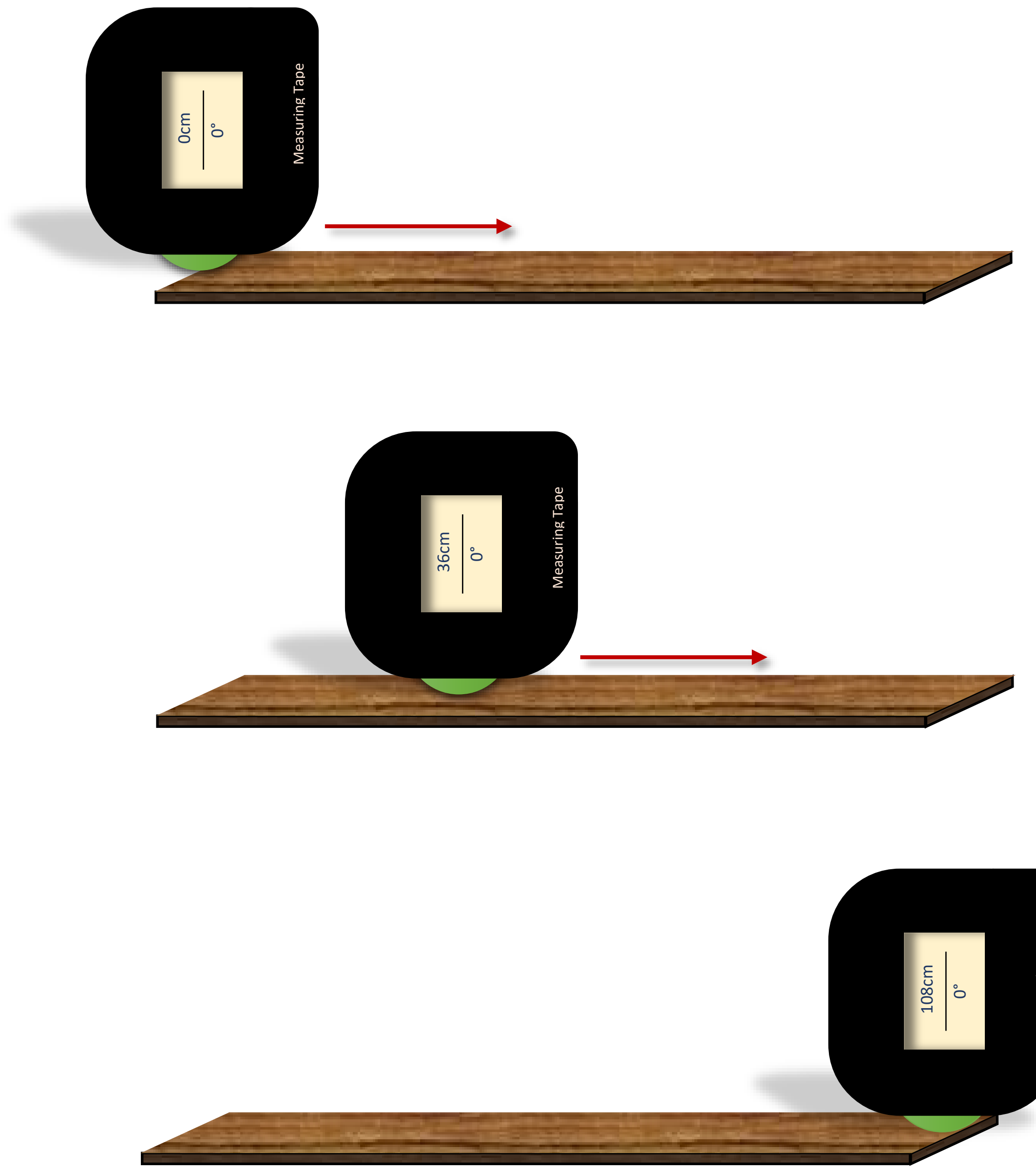


Product Components:

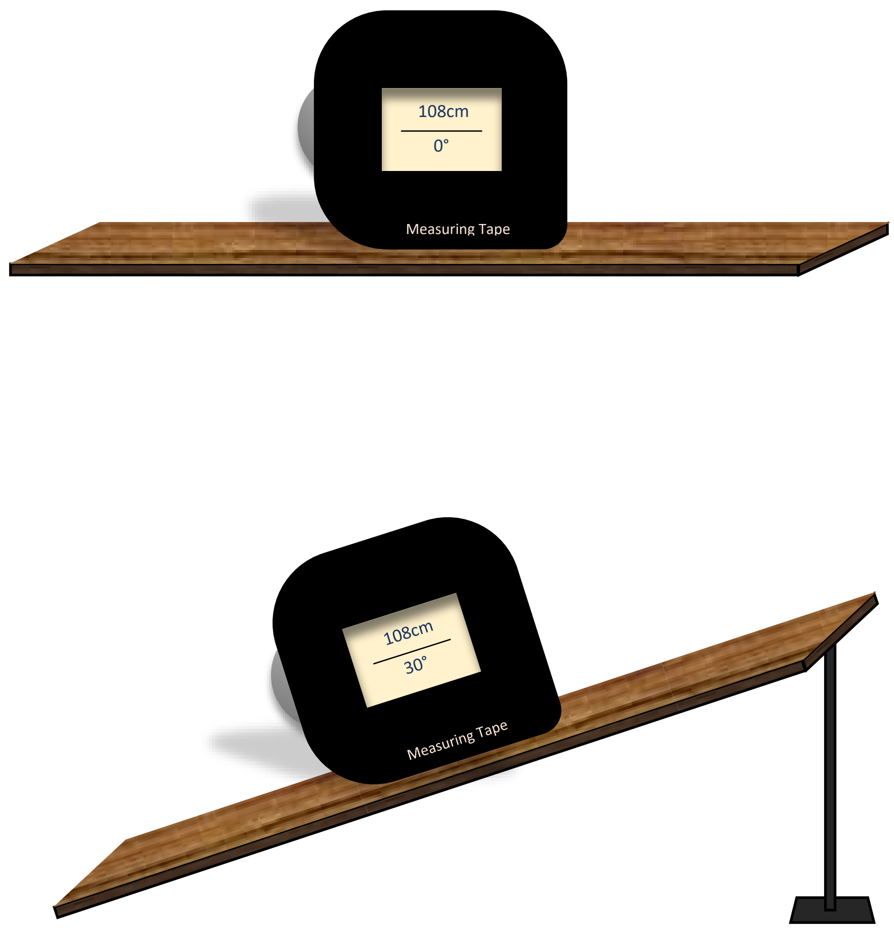
Component		Part No.	Load Power Management
Microcontroller	Silicon Labs Blue Gecko		
Radio	EFR32BG13		✓
Battery	Lithium Ion/Lithium Polymer	LP802036JU+PCM+2 WIRES 50MM Jauch Quartz | Batte Products | DigiKey	
PMIC	BQ25570	BQ25570RGRT Texas Instruments | Integrated Circuits (ICs) | DigiKey	
Buck Converter	TPS62842 Or PMIC internal buck converter	TPS62842DGRR Texas Instruments | Integrated Circuits (ICs) | DigiKey	
Sensor	IMU sensor	BNO005 (To be acquired from Professor)	✓

	Rotary Encoder	Magnetic Rotary Encoder Magnetic Wheel Assembly	✓
	Ultrasonic Sensor	Adafruit Ultrasonic Sensor	✓
HMI	LCD Display	Adafruit SHARP Memory Display Breakout - 1.3" (Acquired from Professor)	✓
	Push Buttons	Available	
Energy Harvesting System	Solar cells	TBD	

Proposed Product Demo:



As shown in the above image, this measuring tape can be used to measure any surface. The wheel encoder assembly installed on the product can be slid over a flat or uneven surface to get size value accurately. This measuring tape will have a high resolution in centimeter because of the use of a precision Rotary encoder with large number of pulse detection in a single rotation.



The above image shows how an angle measurement can be carried out using the product. This angle can be measured in any orientation of the device. The angle measurement will also be highly accurate due to the IMU sensor.

Product Features:

- Free android app to store and manage measurement data
- Bluetooth connectivity of mobile phone with the device
- Rotary encoder-wheel assembly for linear measurement

- IMU sensor for accurate angle measurement
- LCD Display for better user experience
- Energy harvesting mechanism using solar panels
- Load power management by turning on only required peripherals
- Single rechargeable LiPo battery which can power the complete device

Product Specifications:

- Dimensions: 100mm x 70mm
- Weight: 100g
- Wireless range: 100 m
- Size accuracy: ± 1 cm
- Angle accuracy: ± 1°
- Product Warranty: 2 years
- Operating Temperature: 0°C - 65°C
- Internal sensors and peripheral operating temperature:

Sensor	Operating Temperature Constraints
Blue Gecko	-40 to 85 °C
IMU	-40 to 85 °C
Rotary encoder	-40 to 150 °C
LCD Display	-40 to 70 °C

Project Update 2

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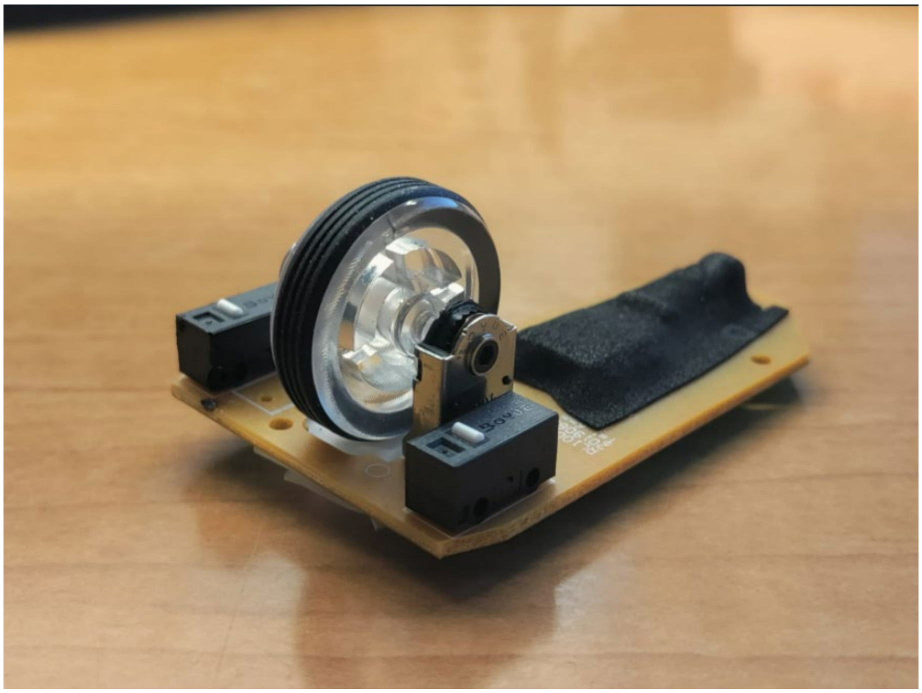
Date: 01/29/2022

1. Activities accomplished in past week:

- Studied mouse scroll-wheel encoder assemblies to decide the decide the mechanical assembly for final product. Disassembled 4 different optical mouses to explore different assemblies.



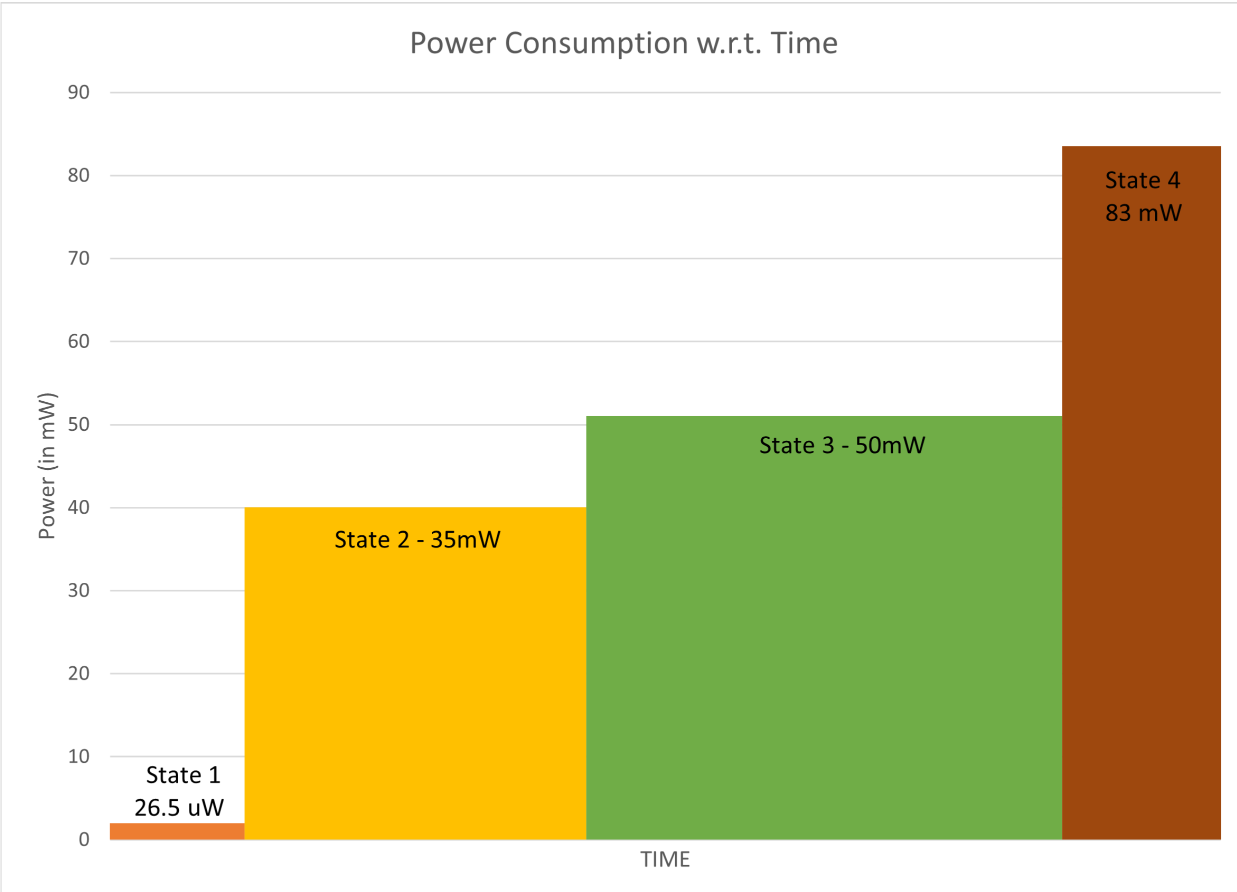
Scroll wheel encoder assembly

- Measured PPR(Pulse per rotation) of rotary encoder and circumference of wheel to estimate linear measurement resolution.
- Finalized ultra-low power Graphic LCD display.
- Estimated total power and energy consumption of the product.
- Worked on project planning and estimated timeline.

2. Activities for the coming week:

- Finalize battery and solar panel based on energy consumption requirements.
- Finalize Power management IC.
- Work on power supply circuit for the product.

3. Energy model for the product:



4. Sensor selection:

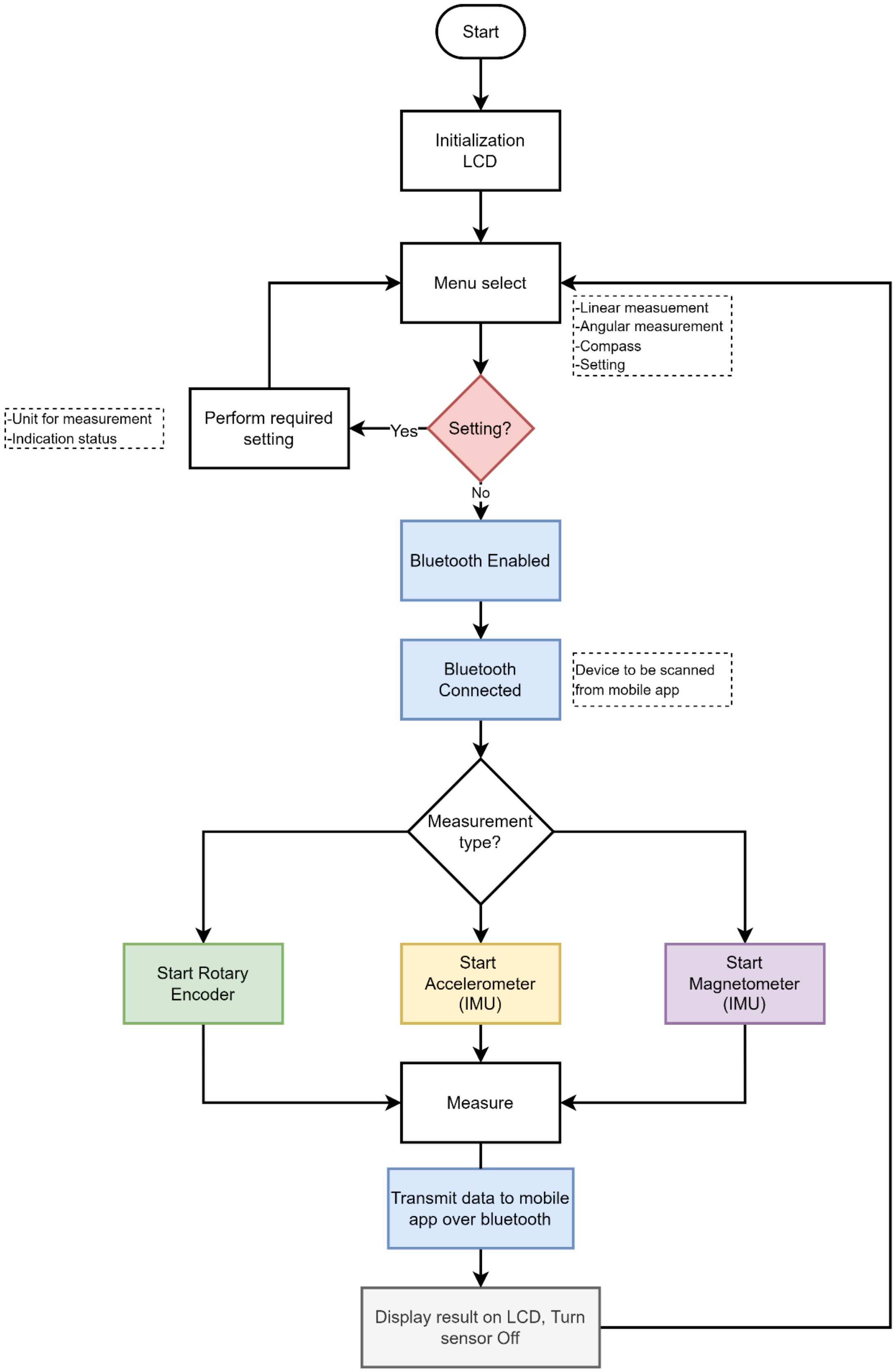
1. IMU Sensor: BNO005
   - This sensor works on I2C as well as UART.
   - We will be interfacing the sensor using I2C as data transfer over UART communication takes longer and even though it consumes less energy, overall efficiency of UART decreases. Moreover, for transfer of larger data bytes I2C consumes the same amount of energy. (These assumptions were made using this reference.)

- This sensor will require external load switch as after start-up it only enters low power mode and suspend mode. (Even in suspend mode it consumes 40uA of current).

2. Rotary encoder
   - This mechanical encoder has just 2 digital pins which can be wired directly as input to the controller. The encoder generated pulses gives the angular position of the axis and can then be converted to digital output.
   - The encoder will also require external load switch as it does not have internal circuitry to turn power off.

Online Project Management using Monday.com

Program Flowchart:



Project Update 3

ECEN 5833: Low Power Embedded Design Techniques

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Team Name: Cubit

Team Members: Rajat Chaple

Saloni Shah

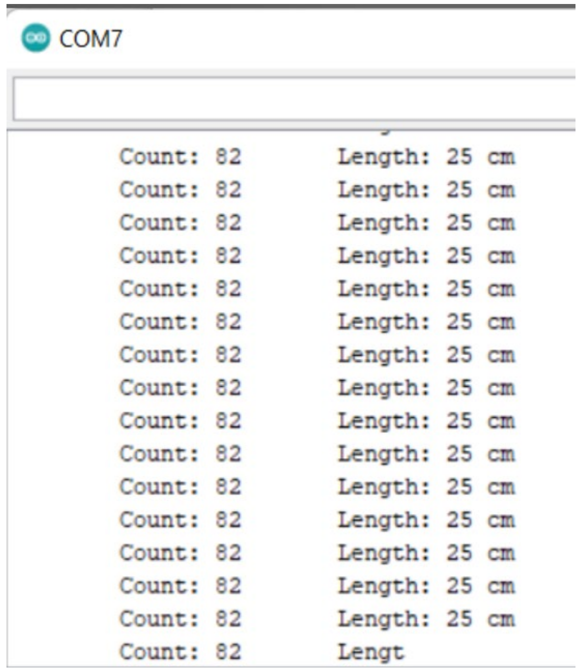
Date: 02/05/2022

1. Activities accomplished in past week:

- Finalized energy storage element (battery) based on energy consumption requirements.
- Finalized Power management IC and buck-converter IC.
- Practically implemented measurement system using mechanical rotary encoder, string-pulley assembly and interfaced it with Arduino. Found out that the rotary encoders have a limitation on how fast it can detect rotations i.e. it can only detect signals correctly at less than 160 rpm.

Assembled a rotary encoder with a string-pulley

Measuring the length of a ruler using the assembly



Arduino serial monitor output with number of pulse counts and calculated length

- Changed the required rotary encoder from mechanical to magnetic due to speed constraints and higher chances of signal misses in the mechanical encoder.
- Finalized required magnetic rotary encoder and ultrasonic sensor for measurement applications.

2. Activities for the coming week:

- Finalized energy harvesting element (solar panel) based on energy consumption requirements.
- Design product power supply circuit.
- Interface LCD display with Blue Gecko Evaluation Module.
- Finalize other required components for the product schematic design.

3. Power Storage Element Selection

- Expected runtime using supercapacitor = 1.36 hours
- Expected runtime using battery = 3 days (8 hours per day)[1]

3.1. Super Cap vs Battery

Required peak current: 25 mA
Average current consumption: 13.68 mA
Average Charge requirement for continuous 8 hours operation: 110mAh
Average Energy Required for 8 hours of operation: 328.4 uWh
Ambient Temperature Conditions: Room Temperature (about 25° C)

Super Cap	Battery
Steep discharge curve	Higher operating time
Large leakage current (30 uA)	Very less leakage current (2%/year)
Cannot handle required peak current	Can handle upto 1A peak current
Lower energy density	Higher energy density
Can operate in very low temperature	Dispenses less energy in low temperatures
Lower ESR power loss	Higher ESR power loss

Design Requirements	Super Cap (Tecate 100F)	Battery (Jauch 480mAh)
Useable Energy	234.5J[2] - 18.6mAh	480 mAh
Peak Discharge Current		1A
Recharge time		2 hours @ 0.5C
2 years of use, 300 charges	500,000 cycles	300 cycles ~ 80% capacity usage
Leakage current or rate	3 uA	Less than 2-3%
ESR	210 mΩ	
Mechanical Dimensions	12.5 x 25 mm	38 x 20.5 mm

[1] Refer attached spreadsheet for calculations
[2] Refer attached spreadsheet

4. Power Management Unit Selection

4.1. Determining the required voltage range for the product

- To decide the operating voltage range for the product, we looked at the input voltage range of the peripherals utilized in the system. The below table shows the minimum and maximum input voltage range of the sensors and MCU.

Sensor	Vin(min)	Vin(max)	Current Consumption
Blue Gecko	1.8V	3.8V	4uA
IMU	2.4V	3.6V	12.3mA
Rotary encoder	3V	3.6V	15mA
LCD Display	3V	5V	4uA

Table 1: Input voltage range for all the system peripherals[3]

- Based on the above calculations, we decided to operate all the peripherals at 3.0V as to utilize maximum possible battery capacity and increase the operating time of the system.
- The approximate range of the supply voltage will be from 3.0-3.6V.

4.2. Determining the power management topology

- Considering that the power source battery gives maximum 3.7V and our required voltage supply for the peripherals is about 3.0V, which is always lower than supply voltage we decided to implement a buck converter to meet our power requirements.
- The primary reason for choosing a buck converter as opposed to a buck-boost is that most Lithium-Poly batteries have a plateau from 3.5-3.6V

[3] IMU datasheet: BNO055 Datasheet (mouser.com)
Blue Gecko datasheet: EFR32BG13 Data Sheet: Blue Gecko Bluetooth® Low Energy SoC Family (silabs.com)
Magnetic Rotary Encoder datasheet: AS5147P-TS_EK_AB ams | Development Boards, Kits, Programmers | DigiKey
LCD Display datasheet: Data+sheet.pdf (adafruit.com)

and very little charge below this plateau, limiting the usefulness of the buck-boost converter and its wide input voltage range[4].

- Moreover, the buck-boost converter also has one additional MOSFET as compared to the buck converter which increases power loss and decreases efficiency of the converter.
- Keeping this in mind, we searched for a buck converter IC, with high efficiency, low quiescent current, low cost, and smaller footprint.
- All these requirements were successfully met by the buck converter TPS62840[5].

4.3. Determining Regulated or Unregulated Power Source

- While deciding whether to use regulated or unregulated power source, we carried out following calculations to understand efficiency of both topologies.

Assumed product usage of 60 minutes or 3600 seconds

Assumed number of measurements in 1 hour, average of 20 measurements

Assumed period for one measurement, average of 13 seconds

On duty cycle = (20 measurements * 13 seconds) / 3600 = 7.2%

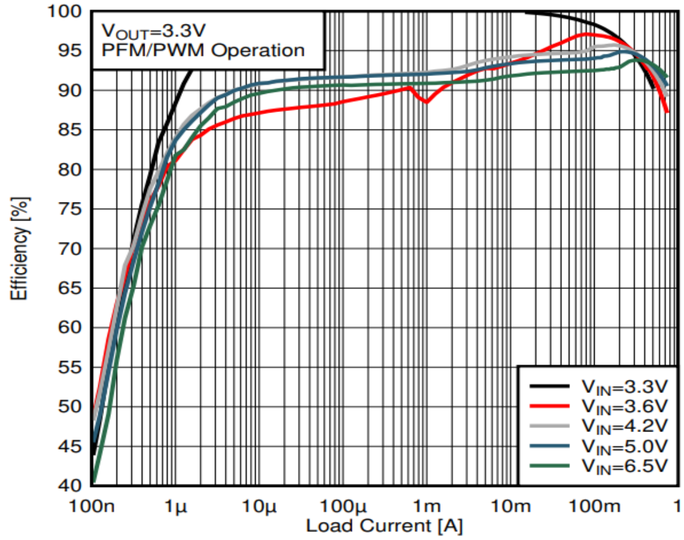
Off duty cycle = 92.8%

<u>TPS62840 Buck converter Efficiency Curve</u>

- Off duty cycle = 0.015-0.020 mA
  Estimated 87.5% efficiency
- On duty cycle = 15-20 mA range
  Estimated 94% efficiency

[4] EETimes - Buck-boost vs. buck converter: it's about battery life in portables

[5] TPS62840 datasheet: TPS62840 1.8-V to 6.5-V, 750-mA, 60-nA IQ Step-Down Converter datasheet (Rev. D) (ti.com)



R_{SET} = 267 kΩ to GND

Figure 19. Efficiency Power Save Mode
V_{OUT} = 3.3 V

<u>For regulated power case (using TPS62840 buck converter):</u>

- On duty cycle
  - TPS62840 efficiency ~3.6V input and 15,500uA is 94% + 0.06uA Iccq
  - Weighted avg power OOB = (On duty cycle * (15500 + 0.06) * 3.0V) / 94%
  - Weighted average power out of battery = 3561 uW
- Off duty cycle
  - TPS62840 efficiency ~3.6V input and 20uA is 87.5% + 0.06uA Iccq
  - Weighted avg power OOB = (Off duty cycle * (20 + 0.06) * 3.0V) / 87.5%
  - Weighted average power out of battery = 63.8 uW
- Total Average Power out
  - Weighted on duty cycle average power + Weighted off duty cycle average power = 3561uW + 63.8uW = 3624.825 uW

<u>For unregulated power case (using Blue Gecko internal LDO):</u>

- On duty cycle
  - Gecko efficiency ~3.6V input and 15,500uA is 83.33%
  - Weighted average power OOB = (On duty cycle * 15500 * 3.0V) / 83.33%

- Weighted average power out of battery = 4017.7 uW

o Off duty cycle

- Gecko efficiency ~3.6V input and 20uA is 83.33%
- Weighted average power OOB = (Off duty cycle * 20 * 3.0V) / 83.33%
- Weighted average power out of battery = 66.81 uW

o Total Average Power out

- Weighted on duty cycle average power + Weighted off duty cycle average power = 4017.7uW + 66.81uW = 4084.5 uW

Increase in battery life using regulated power = 1 - $\frac{3624.825}{4084.5}$

= 11.25%

Based on above calculations, we decided to use a regulated power source since it provides longer battery life. Moreover, we have a higher on duty cycle, higher power on to power off ratio, higher efficiency at light load and low quiescent current which justifies the use of regulated power source.

4.4. Determining the Power Management IC

- The primary criteria for selecting a PMIC were low minimum input voltage limit to support very low voltage from energy harvesting element (solar cell) and efficient boost converter. A simple and efficient circuitry for energy harvester is required which were available in PMIC BQ25570.
- The input voltage supported in this IC is 0.1-5.1V. Also, many typical solar cells have an output voltage of 0.1V.
- Another important criterion is to have a wide range of input voltage from battery to support lower battery power which is 2-5.5V in case of BQ25570.
- This IC also has higher charging current capacity (maximum 285mA) for fast charging from external charger or a USB charging port.
- BQ25570 also has internal Programmable Maximum Power Point Tracking (MPPT) circuitry for optimal energy extraction from energy harvester like solar panel.

- Moreover, BQ25570 has internal boost as well as buck converter to boost low input voltage from the energy harvester and simultaneously regulate the output voltage[6].

[6] BQ25570 internal buck converter vs external TPS62840 buck converter: The TPS62840 buck converter has higher efficiency at low current consumption than the internal buck converter.